Summary Statement

For more than 17 years, the TRMM team conducted innovative precipitation science and developed widely used applications that have greatly benefitted society. TRMM, launched in late 1997, was a joint mission between NASA and JAXA, the Japanese Aerospace Exploration (JAXA) agency. The first-time use of both active and passive microwave instruments and the precessing, low-inclination orbit (35°) made TRMM the world's foremost satellite for the study of precipitation and associated storms and climate processes in the tropics. TRMM met and exceeded its original goal of advancing the understanding of the distribution of tropical rainfall and its relation to the global water and energy cycles. TRMM evolved from an experimental mission focusing on tropical rainfall climatology into the primary satellite in a system of research and operational satellites used for analyzing precipitation characteristics on time scales from 3-hr to inter-annually and beyond. TRMM represented a substantial advancement in precipitation measurement from space achieved through its unique sensor suite, including a precipitation radar (PR), microwave imager (TMI), visible and infrared scanner (VIRS), lightning imaging sensor (LIS), and cloud and Earth radiant energy sensor. This combination of sensors allowed a very comprehensive examination of precipitation systems in a manner unmatched by any other precipitation-measuring satellite system. The TRMM team performed at the highest levels of skill and competence from the beginning of mission development to the end of the science data collection 17 plus years later. Their efforts ensured that TRMM data flowed to users worldwide and provided the key impetus for the current NASA-JAXA GPM mission. As of May 2016, there are more than 3,200 TRMM publications with more than 55,000 citations.

Key mission management successes occurred in the 2001 and 2004 time frames. First, by early 2001 (three years into the mission), TRMM scientists faced an early end of the mission in 2002 or 2003 due to quickly diminishing fuel. After careful analysis of the benefits and drawbacks, the TRMM science teams (U.S. and Japan) proposed increasing the orbit altitude by about 50 km in order to decrease atmospheric drag and extend mission life. After extensive review, NASA and JAXA agreed to the mission extension plan and ordered the boost to the higher altitude. *The boost to 402 km was carried out in August 2001* and TRMM operated at that altitude thereafter. Second, in 2004, NASA was considering ending the mission in order to do a controlled re-entry. Because of excellent leadership by the TRMM team (led then by Dr. Robert Adler), and with a National Academies report indicating the benefits of an extended mission, NASA waived the controlled re-entry. As a result of both actions, TRMM lasted an additional 12 years, collecting data essential to reducing uncertainty in TRMM's rainfall climatologies.

The following provides a more detailed summary of the TRMM team's most significant achievements.

A) Accurate precipitation climatology. TRMM data have allowed: Production of a long benchmark climatology of rainfall in the tropics, narrowing considerably the range of uncertainty in previous space-based rainfall estimates; description of temporal variations in rainfall, from diurnal to interannual time scales, including important variability associated with the Madden-Julian Oscillation and with El Nino Southern Oscillation (ENSO); estimates of vertical profiles of latent heating in the tropics, a key driver for global atmospheric circulation; and identification of potential impacts of humans on rainfall related to processes associated with urban heat islands, deforestation, and aerosols. This TRMM climatology has provided an important benchmark for global climate models including accurate annual, monthly, and diurnal tropical rainfall averages to which models can be compared.

B) Precipitation diurnal cycle. TRMM allowed the heretofore-impossible quantification of the diurnal cycle of precipitation and convective intensity over land and ocean tropics-wide on fine scales (0.25°). In addition to studies characterizing the diurnal cycle on global scales, the accumulation of 17 years of data allowed for studies of the diurnal cycle at regional scales.

C) Tropical cyclones. TRMM data have been heavily used by operational forecast centers and the tropical cyclone science community, and have played an important role in the monitoring and analysis of tropical cyclones. The data have helped establish key characteristics of the distribution and variation of rainfall in tropical cyclones as a function of intensity, stage of development, and environmental conditions. Both sea-surface temperature (SST) and rainfall data from TRMM were often utilized to investigate the mechanisms responsible for storm genesis and rapid intensification. TRMM's higher spatial resolution and frequent sampling in the cyclone-important 10-37° latitude bands meant that its data were frequently used for detecting the location and intensity of tropical cyclones, allowing for ~500 tropical cyclone center fixes per year by operational centers.

D) Tropical convective system properties. TRMM PR, TMI, VIRS, and LIS supplied information for a Cloud and Precipitation Feature (CPF) database, created by the University of Utah, that provided a definitive climatology of the distribution of convective system characteristics (e.g., horizontal size, depth, and intensity) which is very useful for searching and sorting historical rainfall events. The CPF database was used to document the global distribution of tropical deep convection, and to examine regional, seasonal and diurnal variations of the rainfall contributions from various precipitation features. PR data was frequently used to characterize the vertical structure of convective systems in many climatologically important regions.

E) TRMM Applications. With the TRMM satellite producing the best instantaneous rain estimates at the time, those estimates were used to calibrate or adjust rain estimates from other satellites to provide analyses at higher time resolution than available from one satellite. The TRMM multi-satellite precipitation analysis (TMPA) provided calibrated precipitation estimates from multiple satellites, as well as gauge analyses where feasible, at fine scales (0.25° × 0.25° and 3 hourly). Near real-time versions of the TMPA product were provided to operational agencies and other users. The rainfall products were used for a variety of important studies, including validation of meteorological reanalyses, hydrologic modeling, analysis of oceanic precipitation systems, characterization of monsoon convection, closure of water budgets, as well as for other hydrometeorological applications. The TMPA was widely used for applications related to floods, landslides, agriculture, re-insurance, and disease. TRMM's applications spanned several U. S. agencies including NOAA, U.S. Geological Survey, Department of Interior, Department of Defense, among others.

F) Lightning. LIS has led to a detailed global mapping of lightning distribution and its seasonal variations. TRMM's lightning and rain information together have allowed quantification of the lightning/convection relation for land and ocean. Knowledge of lightning flash size/energy and flash type (ground or cloud flash) has led to better determination of lightning nitrogen oxides emissions.

The excellent design, implementation, management, and scientific achievements of the TRMM mission make it well reserving of recognition for the Pecora Award.

Supplementary Material

Excerpts from a National Research Council of the National Academies Interim Report on "Assessment of the Benefits of Extending the Tropical Rainfall Measuring Mission: A Perspective From the Research and Operational Communities", National Academies Press, 2006, 103 pp.

"TRMM has achieved its original science goals and produced a greater than expected range of scientific results in

1. climate and weather research (e.g., a reliable seven-year climatology of the mean annual tropical rainfall and its interannual and diurnal cycles; fundamental new information on the synoptic climatology of tropical wather systems, e.g., the first detailed precipitation and latent heating profiles throughout the tropics and subtropics, first detailed convective and stratiform rainfall structure, and a description from space of the fine-scale structure of rainfall systems that can only be determined from the PR data; understanding of how sea surface temperature patterns modify precipitation through air-sea interaction; quantitative documentation of the precipitation patterns; mapping sea surface temperature through clouds for improved climate records; demonstrating the effect of pollution and other human influences on precipitation formation); and
2. applied research (e.g., a wealth of climatological and diagnostic information on tropical rainfall; insight on the physical processes of precipitation formation; unique, fine-scale information on hurricane and typhoon structure linked to rapid intensification; calibration of a long-term satellite precipitation dataset and nultisatellite three-hour analyses; experimental tropical cyclone forecast methods; enhanced sea surface temperature nowcasting applications using TMI data; integration of TRMM data into forecast model initialization procedures; enhanced understanding of tropical cyclone inner eyewall dynamics and tropical cyclone intensity).